THE GEOLOGY OF GOZO

George Zammit Maempel

In the distant past, all knowledge that did not relate to God was considered mundane and was dumped under the heading **Geology** (*Geos*: earth; *logia*: study of) — in contradistinction to Theology (*Theos*: God). It was not before the second half of the 16th century that Geology was used in its modern, restricted sense, in a manuscript attributed to Juanelo Turrientes (Lopez de Azcona, 1987: 48). In the printed form, the term 'Geology' appeared a century later when M. P. Escholt published his *Geologia Norvegica* in 1657.

Geology, as we know it today is a science related to the study of rocks and to the natural processes/forces acting upon them. Broadly speaking the geology of Gozo is not much different from that of Malta, but there are a few sedimentary structures as well as some geomorphogical and tectonic features which are more evident on one island than on the other.

Gozo is the second largest and the most northern island of the Maltese archipelago, which lies on a Northwest-Southeast axis, with a slight Northeast tilt. As a result of this gentle tilt to the north-east, we can see, to south-west of Gozo, Ta' Ċenċ cliffs, made of rocks from the lowermost Formation on the Maltese Islands, towering to a height of about 140 meters above sea level, whilst on the north, at Marsalforn, the overlying Globigerina Limestone is brought down to sea level. Further westwards on the same coastline, Wied il-Għasri, excavated in the lowermost geological Formation (Lower Coralline Limestone), is invaded by the sea to form a miniature Fjord.

Origin of Rocks

Like Maltese rocks, Gozitan rocks are of marine sedimentary origin, having been deposited on the bottom of a warm sea, at various depths and distances from a continental mainland, during the Oligo-Miocene epoch of the Tertiary Period of Geological Time, during an age range of about 30 - 7 million years before present.

With time these marine deposits solidified and became rocks. Then, following severe tectonic disturbances (i.e. great pressures) resulting from the impact of the African and Eurasian Plates, they were raised to the surface as the tips of a submarine ridge that was formed in what is now the central Mediterranean. The ridge extends between Sicily and Tunisia, and divides the central Mediterranean into two unequal hydrographical basins.

The rock types/Formations numbered, in the order of their deposition, i.e. starting from the oldest, are: (1) Lower Coralline Limestone; (2) Globigerina Limestone; (3) Clays; (4) Greensand; and (5) Upper Coralline Limestone. In some places, these marine exposures may be overlain by patches of much younger terrestrial deposits of Pleistocene age ('Ice Age' deposits).

In Gozo, these Pleistocene beds were first recorded in 1874 by Captain F. W. Feilden and Dr E. C.. Maxwell. It is very probable that Maxwell lived in the region of San Lawrenz, for an inlet and a stretch of land with an overlying farmhouse in this Western part of Gozo still go by the name of Ta' Maxwell. There are only a few places in Gozo where you can see, at a glance, the entire sequence of rocks forming the Island. Il-Miġra is one of them. None of these, however, gives a clear picture of the succession.

Compared to Malta, Gozo has a much more varied geology, with greater relief contrast and more extensive outcrops of clays. This latter factor has an effect on its water supply and consequently on its vegetation, rendering the Island much greener than Malta.

Historical Aspects

The general geology of Gozo was first outlined in 1843 by the young Royal Navy Lieutenant and able marine surveyor, Thomas Abel Brimage Spratt (1811-1888) — later Vice-Admiral T.A.B. Spratt C.B., F.R.S.

Spratt's scientific contribution in the field of Maltese and Gozitan geology was the subject of two recent publications by the present author (Zammit Maempel, 1986, 1989a).

Spratt's 1843 publication includes a 'Note' and a 'Report' on Maltese Fossils by Edward Forbes, Curator of the Geological Society Collections, as well as an outline map of the Maltese Islands (135 mm x 230 mm). Besides marking the location of two of Gozo's main faults, Spratt's map gives also three Lines of Section: one along the long axis of the Maltese Islands, one across Gozo (Forna - Xlendi, passing through Żebbuġ, Marsalforn Valley, Ramla Valley and Chambray) and another across Malta. In the 1854 edition of this work (a copy of the 1852 edition, the geological sections are in colour.

During recent years, the geology of Gozo has received considerable attention. Great advances have been made particularly in the field of its tectonics (study of the features resulting from deep natural pressures) — a subject that was originally tackled scientifically in some detail by Hobbs in 1914. It was Illies of the Geological Institute of Karlsruhe University, however, who made the first kinematic interpretations of Maltese and Gozitan tectonics (Illies, 1980, 1981). Reuther followed very closely in the foot steps of Illies, his former chief and master, and made further advances in the subject, recording his findings in a thesis and a number of scientific papers — some of which deal specifically or mostly with Gozo tectonic structures (Reuther 1983, 1984, 1993).

In former times, tectonic features were studied merely as local geological events. In recent years, however, these have been studied and interpreted also in the context of their relationship to other global and Mediterranean features — particularly the Pantelleria Rift System in the central Mediterranean region. The Pantelleria Rift system, located between Sicily and Tunisia and occupying an unstable area about 380 km long and 100 km wide, is responsible for the Magħlaq Fault in Malta. It is still affecting the Maltese Islands tectonically. In fact, the last two earthquakes affecting these islands were localized in this still unstable zone. It was the Maghlaq Fault (which extends also to Ras Bombarda in Gozo) that turned Filfla (a one-time high ground on the Maltese mainland) into an island 5 km away from coast.

In addition to the advances made in the field of its tectonics, Gozo has registered great progress also in the study of other geological subjects including sedimentation processes (Pedley *et al.* 1976, Bennet 1980), karstic (limestone solution) features and fossils. Solution subsidence structures, like Dwejra, were first investigated scientifically and in detail by Pedley in 1974, whilst Gozo fossils, have received, and are still receiving, considerable attention by various research workers. In recent years, the echinoids (sea urchins) of Gozo have been investigated mainly by Rose (1974) and by Challis (1980); the calcareous nannofossils by Hojjatzadeh (1978) and Kienel *et al.* (1995) and the Miocene Pteropod molluscs — a relatively new field of local research — by Rehfeld and Janssen (1995).

The great progress made in the study of the tectonic features of Gozo, necessarily followed great advances made in the related field-mapping of the outcrops and fault lines of that island. Newly acquired information was added to the already available basic surveys and this culminated in the preparation of much better and more detailed geological maps. The 1955 field work by a team from Durham University (M.R. House, K.C. Dunham, A.A. Wilson (on behalf of B.P. Exploration Ltd.) lead to the production of the B.P. Geological Map of Gozo and Malta (1957) on a scale of 1: 31, 680 (2 inches to 1 mile). This was followed, in 1964, by another one prepared by J.C. Wigglesworth as part of his PhD thesis. Wigglesworth's map, which showed also the various subdivisions of the Globigerina Limestone, was never published but has served as a basis for further geological maps of the Island. A very slight revision of it was published by Pedley in 1976 and this was reproduced by Zammit Maempel in 1977.

Further detailed field-work on the rock outcrops and on the tectonic features of Gozo have since resulted in the preparation of two other detailed Geological Maps of Gozo. The first of these (230 mm x 90 mm) was prepared in 3-D by Troschke of the Institut für Geologie und Paläontologie, Technische Universität, Berlin, as a *studienarbeit* for his Diploma in Geology. It was published in Reuther and Adam (1993: 14, Abb. 19) and was accompanied by 3-D geological map-blocks of East Gozo, South West Gozo and North West Gozo (p. 16, Abb. 21; p. 20, Abb. 26; p. 24, Abb. 30 respectively).

The other recent geological map, dated 1933, was issued by the Oil Exploration Directorate of the Prime Minister's Office in 1994 and is the first published geological map of the Island to show the outcrops of the various Members or Divisions of the local rock Formations. It is based on surveys (1 : 25,000) prepared by H. Martyn Pedley of the School of Geography and Earth Resources, University of Hull in 1992 – with corrections made by Godwin Debono and Saviour Xerri of the Oil Division Directorate, Prime Minister's Office, Malta, in 1993.

Characteristic Fossils of each Rock Type

Each of the geological Formations has its own particular or characteristic fossils – i.e. the remains, imprints or products of organisms (plants or animals) that existed in the geological past. Fossils are as old as the rocks containing them, so that specimens found in the lowermost Formation (of Upper Oligocene, Chattian Age) are about 25-30 million years old and those embedded in the youngest rocks (Upper Coralline Limestone, of Upper Miocene Age) date back to over 5.5 million years, whilst those contained within the intervening rock Formations are of an age somewhere in between. The most common and characteristic fossils of each Formation will be reviewed in chronological order of deposition of the Formations.

It should here be recorded that in the Maltese Islands, fossils are protected by Law (The Antiquities Protection Act), so that their unauthorised collection is illegal.

Lower Coralline Limestone (Maltese: Qawwi ta' Taħt, Żonqor)

The most characteristic fossils of Gozo's oldest rock Formation (Lower Coralline Limestone) are the tubes of the teredinid bivalve *Kuphus melitensis* Zammit-Maempel. In 1993, this fossil was described as a species new to science on the basis of its calcareous tubes, valves – two shells at its anterior or lower end – and pallets – the two hard internal structures at its upper or posterior end (Zammit Maempel 1993). Its cylindrical tubes were figured for the first time from the Maltese Islands in 1977 (Zammit Maempel 1977), whilst their Indo-Pacific affinity was noted in 1979 (Zammit Maempel 1979).

In 1989 a record was made of the lore attached to these stones by Maltese hardstone quarry workers who refer to these structures as *sallur* (petrified eels) dating back to the Universal Deluge, *terħa* (sash) or *dud* (worms) depending on their shape (Zammit Maempel 1989b). In Gozo, tubes of *Kuphus melitensis* have been located at Ta' Ċenċ, Ħondoq ir-Rummien and Mġarr ix-Xini, but they will, undoubtedly, be found also elsewhere. Large accumulation of these tubes forming half metre thick bands (*Kuphus* Beds) traverse the Island of Malta, and probably also Gozo, at about 75 metres below upper limit of the Lower Coralline Limestone. The author could not locate the *Kuphus* Beds in the Mġarr ix-Xini gorge where in the 1860s, Andrew Leith Adams encountered the tubes 'in large numbers' (Adams, 1870: 271, footnote 19).

Lower Carolline Limestone / Globigerina Transition Zone (Scutella bed).

Between the Lowermost Formation and the overlying Lower Division of the Globigerina Limestone there is a transition zone that abounds in fragmented and/or complete specimens of a thin, flat sea urchin (sand dollar') called *Scutella subrotunda* Leske . Hence, this transition zone is scientifically referred to as the '*Scutella* Bed'.

In Gozo, the *Scutella* Bed seems to be more constant than in Malta — where it is, at times (e.g. at Fomm ir-Riħ), replaced by a thick bed of bivalves and bryozoa. The abundance of the typical flat thin sea-urchins exposed at surface in the Dwejra area (now a Protected Natural Heritage Site) is a great tourists attraction. The *Scutella* bed transition zone — which in Gozo is characterised also by pockets of the unusual irregular echinoid *Apatopygus* (Figure 1) in its upper regions — leads into the overlying Lower Division of the Globigerina Limestone Formation.

Globigerina Limestone

The Globigerina Limestone Formation owes its name to the millions of tiny (microscopic), one-celled, planktonic marine creatures (called 'Globigerina') composing it. They still thrive in modern open seas and as their shell is riddled with holes or *foramina*, they are classified with the *Foraminifera* (meaning 'bearers of *foramina* or holes').

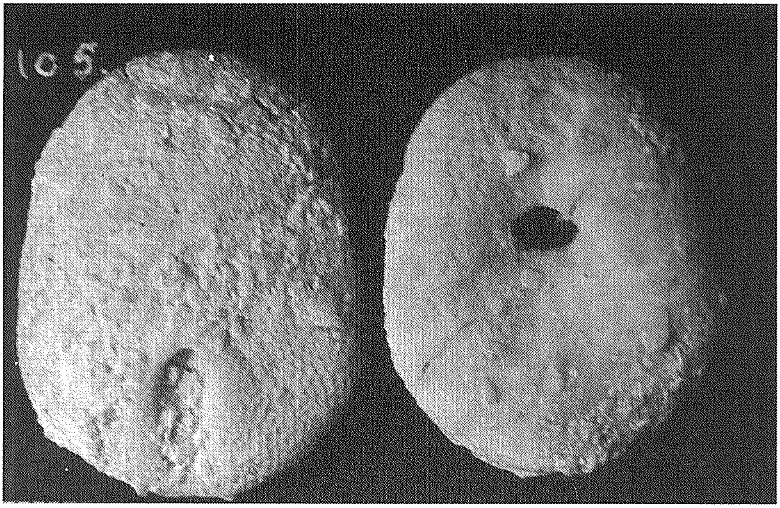

Figure 1. The fossil echinoid *Apatopygus*. *Scutella* bed, Wied il-Miela. This is the first time that this fossil sea urchin from Maltese Archipelago is being illustrated. *Photo: George Zammit Maempel.*

A number of horizontal phosphorite levels (formerly called 'Nodule Layers' / 'Nodule Beds') characterise the Globigerina Limestone formation. Two of these levels occur on both Islands and divide the formation into three lithological Divisions, known respectively as Lower, Middle and Upper Division. The Lower Division (*Franka*) is the source of our soft honey-coloured building stone; the Middle Division (Qargħajja, Bajjad) is whiter and more clayey and has no practical use as a building stone but served once as a good source of chert (an impure form of flint) for prehistoric man's implements.

The lowermost parts of the honey-coloured Lower Division of the Globigerina Limestone are characterised by a 2 - 3 metre-thick, dense net work of branching tubes. These are generally brought out in relief through differential weathering. In former times the structures were erroneously thought to represent branching roots, but they are now known to be burrows made by sea animals (like Callianassid crabs) that existed millions of years ago. Being products of animals that existed in the geological past, they are likewise considered to be 'fossils' and are generally referred to as 'Ichno fossils'.

The Upper Division (*Tal-Kwiener*) — which has a certain resistance to fire — was formerly the source of slabs for lining ovens and for the manufacture of the small cooking stoves (*Kenur*/plural *Kwiener*). Gozo was the chief source of this material.

The most characteristic and most popular fossils of the Globigerina Limestone Formation are probably (1) the heart-shaped sea urchins *Schizaster eurynotus* Agassiz (Figure 2), and (2) the very peculiar sea urchin *Brissus crescenticus* Wright, whose lateral ambulacra are arranged in the shape of two crescents placed back to back, and the serrated teeth of the Giant White shark, *Carcharodon megalodon* Agassiz. Teeth of this monster shark are very common in the Globigerina, but occur also in the Clays and in the Greensand Formation. The largest one recovered locally measures 7 inches along its margins (Adams 1870:139) and – as it is generally estimated that one inch of tooth represents a 6-10 foot shark – the proud bearer of this large tooth (now at the Natural History Museum, London) must have been a monster shark with a length of between 42 and 70 feet (14 - 23 metres). The heart shaped urchins occur in large numbers in the lower parts of the Lower Globigerina Limestone Division, and are characterised by five petal-shaped furrows (*ambulacra*) the anterior three of which are much deeper and longer than the posterior pair).

Clays (Maltese: Tafal)

The Clays contain a number of fossils but these are generally very badly preserved and covered with a thick rust-like (limonitic) coating. The small beautiful members of the Cephalopod genus *Aturia* are usually an exception, for they are generally well preserved. *Aturia* is a member of the Octopus/Squid/Cuttlefish/*Nautilus* group, but, unlike the other members of its group, it is now extinct the world over. Like the Pearly *Nautilus* of the Indo-Pacific, *Aturia* is chambered and the wavy walls of its chambers can be seen very clearly on the outside of the fossil shell. The organic tube that once connected its chambers to enable the animal to regulate its buoyancy has now disappeared. What remains of it is just the opening (siphuncle) in the chambers' partition walls.

Other common and characteristic fossils found in the Clays are single

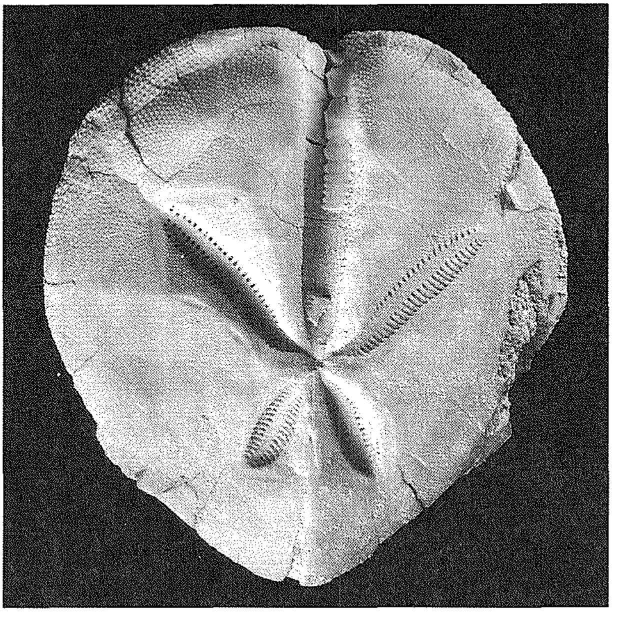

Figure 2. Fossil heart-shaped sea urchin *Schizaster eurynotus* Agassiz. *Photo: George Zammit Maempel.*

corals of the genus *Flabellum*. Their fan-like appearance, wedge-like shape and their oval 'base' — from whose margins radiate inwards a number of unequal spokes (septa)— are features which render these fossils unmistakable.

Greensand (Maltese: Ramli / Rina).

Orange-coloured, thick-shelled echinoids (sea urchins) called *Clypeaster* are probably the most characteristic fossils of this Formation. They vary considerably in size and shape — some resemble 'Mexican hats' but most are in the shape of rimless conical mounds. Both varieties have now disappeared from Maltese waters and survive mainly in the Indo-West Pacific region.

Upper Coralline Limestone (Qawwi ta' Fuq)

This relatively young Formation abounds in casts of the boring bivalve mollusc, *Lithodomus lithophagus* L. known locally as *Tamal tal-Baħar*. The species is still extant in modern rocks and in stones on shallow sea bottom and, being edible, it is much sought after by certain divers. The animal settles in the stone or rock when it is still very young, gradually enlarging its limestone chamber with the aid of acid secretions. Its only connection with the outside marine world are two joined siphons emerging from the chamber through a dissolved canal that soon takes their shape. The siphons represent a larger inlet and a smaller outlet tube, serving respectively for procuring food and for discharging waste material. The animal's home becomes its coffin, for from its chamber, it will never come out again unless somebody breaks the rock or stone enclosing it — and this is what the divers do.

One other interesting fossil of the Upper Coralline Limestone is a small very fragile sea urchin which is probably the most beautiful of all the fossils of the Maltese Islands (Figure 3). It was first recorded to science by the British (Cheltenham) surgeon-naturalist Thomas Wright in 1855, and was by him called *Cidaris melitensis*, the Maltese crown. (Wright 1855). Unlike many other members of its family, this fossil species migrated into the Mediterranean from the Atlantic Ocean and not from the Indo-Pacific.

Its closest modern Maltese representative is *Stylocidaris affinis* Philippi (Maltese: *Raddiena*), which is a great headache to local fishermen, as its long spines (2-3 times as long as its width), tend to get entangled in their deep-sea fish nets.

In the Upper Coralline Limestone of Malta, complete specimens of this fossil sea urchin are limited to a particular Member of the Formation but, owing to its great fragility, the test is hardly ever found in a perfect state of preservation. In Gozo, the present author has never encountered a complete specimen but only isolated plates. Ancient writers referred to these isolated plates as *Mammelle di San Paolo*, because of their resemblance to a human nipple with surrounding areola — ir-ras u l-ħaġra.

Another characteristic fossil of the Upper Coralline Limestone is the sea urchin *Brissus oblongus* Wright, easily recognised from the typical horizontal arrangement of its antero-lateral pair of furrows (*ambulacra*) — resembling a man with feet apart and hands outstretched. This fossil species, which was first described to science by the medical doctor-

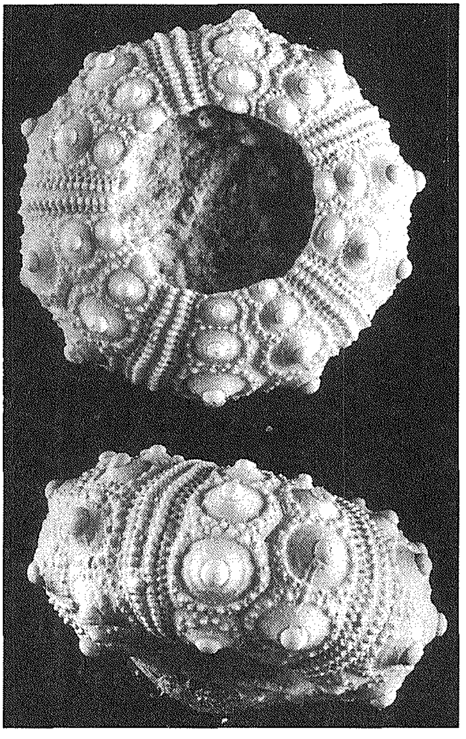

Figure 3. ***Cidaris melitensis*** **Wr. fossil sea urchin from the Upper Coralline Limestone.** ***Photo: George Zammit Maempel.***

scientist Thomas Wright in 1855, has not changed much in appearance since Upper Miocene times, several million years ago. It is still to be found buried in sandy and silty bottoms, around the Maltese Islands.

Marine, Sedimentary Origin of Rocks

It will be noted that all the above-mentioned fossils recovered from the individual rock Formations of the entire geological sequence of the Maltese Islands are of marine organisms. This goes to prove that the rocks containing them must likewise be of marine origin. In addition, a careful look at the local rock Formations reveals that they are layered/bedded/stratified and that these layers/Beds/strata are generally horizontal - a sure sign of their sedimentary origin. Notwithstanding that horizontal stratification is a characteristic of all sedimentary rocks, the initial horizontal alignment is not always maintained. It could be altered both during deposition of the sediment (giving rise to irregular deposition called 'cross bedding') or after deposition and hardening of the deposit into rocks (giving rise to dipping or bending). Disturbances occurring after rock-formation are invariably associated with nearby tectonic activity and are the effects of enormous natural pressures or stresses. One of these effects is faulting – where the continuity of the strata is interrupted as a result of a fracture + movement of the parts in relation to each other. The study of these natural forces / stresses and of the processes acting upon rocks constitutes the second part of the definition of the term 'Geology' (the first part being 'the study of the Rocks').

Natural forces/Stresses and Processes

For the purpose of this study, consideration will be given solely to the effects of the elements and of the natural pressures/stresses upon rocks. Like the wind, natural pressures and stresses are not visible and one becomes aware of their presence only by noting their effects. At times, however, these may be difficult to interpret and a case in point is the disorderly upheaval of large blocks of rocks at ix-Xfar, east of Daħlet Qorrot, in the region of Qala in eastern Gozo (Figure 4).

Here, large blocks of the hard phosphatic bed that separates the Lower from the Middle Division of the Globigerina Limestone — P.B. 1, formerly known as Nodule Layer/Bed 1 or 'N.L.1' — have been dislodged from their base, overturned and scattered or piled up on each other in utter confusion. The blocks —each of which is about 0.5 metre thick and often several metres long — have literally 'popped out' of their original position and are, consequently, technically described as a pop-up feature.

This not-so-common geological phenomenon is the result of the still active stress pattern caused by the lateral pressure (associated with the nearby Qala fault) acting on rocks of two different consistency. The process must have occurred following the unloading (by erosion) of the overlying burden (i.e. the rocks overlying the very hard phosphatic bed) during Holocene times (Figure 6).

It will be noted that, by contrast, the overlying softer Middle Globigerina

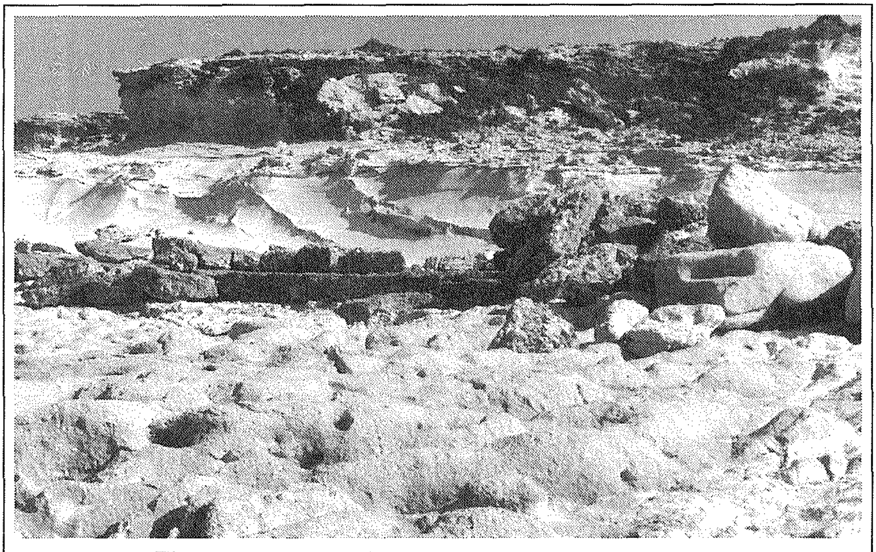

Figure 4. Pop-up features at Ix-Xfar, Daħlet Qorrot, Gozo. ***Photo: George Zammit Maempel.***

Limestone Division behind this denuded area is merely squashed and cracked. With time, the tension cracks got infilled with calcite which, being harder than the limestone, have since been brought out in relief by differential weathering and erosion.

At times, the natural forces do not crush the rocks, but merely pull them apart as if to slide them along a horizontal plane. In such cases there develop on the surface of these rocks a very characteristic pattern of cracks and parallel markings, with open tension joints set at an angle to the horizontal. Such features —which are known as 'Riedel shear structures' (after the man who first described them) — have been likened to 'cracks in the roof due to movements in the basement'. Some of these features in Gozo were first described and figured by Vossmerbaumer (1972).

Excellent examples of these geological features can be viewed on the wave-cut platform in the Lower Globigerina Limestone Division west of Marsalforn, in the region of Nagħaġ il-Baħar. Unfortunately, many of these are being obliterated by black tyre marks of cars /jeeps that are allowed to drive on the rocks by the coastline.

When the breakage is not just a superficial crack (as the Riedel shear structures), but a long deep fracture, the opposing parts may undergo movement in relation to each other. A fracture with movement constitute a fault. Every fault has a location, extent and orientation and if such features of each known fault are projected on to an outline map of the Maltese Islands, the result will be a Tectonic map of these islands. As the commonest form of fault in Malta is a sliding down movement that generally results in a step-like structure at surface, the local name for a 'normal fault' is *Tarġa* (step). The terminology is still preserved in the local toponomy — San Pawl tat-Tarġa and San Ġużepp tat-Tarġa, both of which stand on the Great Fault of Malta. The down throw of a fault may be only a few centimetres or several metres (as at ix-Xaqqa, Malta).

When a large block of rock slides over another one, there is generation of heat with consequent melting and alteration of both rock faces — making them very hard and shiny. In addition, the pressure caused by the irregular surface of the sliding block leaves vertical scratch marks, called *Slickensides*, over the surface of its counterpart.

As no very long and impressive slickensides were encountered in Gozo, the ones seen at Ix-Xaqqa (along the Magħlaq Fault on the way down to Għar Lapsi, Malta) are being referred to here. These give a good idea of the changes seen on the rock face as a result of the faulting. At this particular site, a 6 km block of Upper Coralline Limestone slid down over the Lower Coralline Limestone surface for a distance of about 250 m. Faulting brought the Upper Coralline Limestone down to sea level and turned Filfla (a one-time highland on the Maltese mainland) into an island about 5 km away from the Maltese coastline. The very hard shiny surface, the vertical scratch marks and the flutings on Lower Coralline Limestone surface (Slickensides) are here very clearly visible.

Very occasionally, the sliding movement may be horizontal. In the Mġarr ix-Xini region (a short distance below the pine trees) there are slickensides which started vertically but which at a particular point in time, shifted their course sub-horizontally. This is a sure indication of a rotation of the axis of the fault during the faulting process.

At a different site along the Mġarr ix-Xini valley, starting only two metres above soil level and continuing upwards on the rock face of the

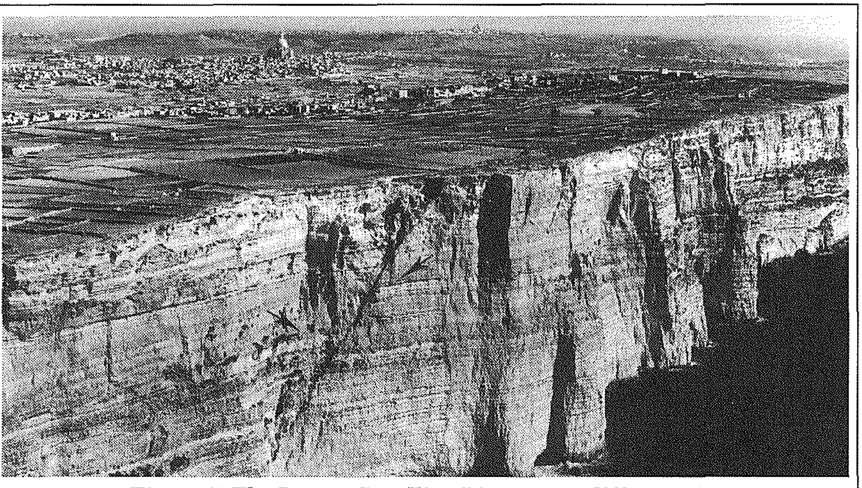

Figure 5. The Lower Coralline Limestone cliffs at Ta' Ċenċ. Note the characteristic sheer cliffs with caves at sea level and a fault without surface expression.

valley wall for some more metres, there is a series of crescentic cracks. These peculiar features are an indication of the severe natural tension or stresses sustained by these rocks in connection with the nearby Qala fault.

Notwithstanding that a Fault or dislocation normally generates a 'step', the deposition of sediment after the occurrence of the fault may easily mask the evidence at the surface. Complete erosion of the former higher surface (step) by the elements may be another reason for the lack of evidence of the faulting. The fault shown in the aerial view of Ta' Ċenċ Cliffs (Figure 5) has a down-throw of about 30 metres and yet there is absolutely no evidence of this movement at surface. People can just walk over the fault line without noticing any difference in level. In this case the cause is not faulting before deposition of the overlying strata (as even the uppermost strata are mismatched), but the complete erosion of the higher surface to match exactly that of its downthrown counterpart. Compared to Malta, Gozo has markedly greater relief contrast features and this is due to the extensive erosion, solution and down-cutting of the rocks on that island by the elements. The Gozo landscape is thus characterised by hills with a flat- topped Upper Coralline Limestone capping (*mesa*). Wherever this protective hard capping has been broken down as a result of the elements and of the unstable underlying clay formation, conical or wedge-like mounds of clay – with or without traces of the overlying hard limestone capping – are common features (eg mound *Is-Salvatur* at Marsalforn).

Besides the visible erosion just mentioned, there is also another type of erosion that is underground and invisible. As the Maltese Islands are a limestone country, and limestone is dissolved by water, it is quite common to have large solution (Karstic) cavities developing underground — even at great depths. When such structures ultimately collapse and subside, they form circular depressions like Maqluba in Malta and Dwejra in Gozo.

An aerial view of western Gozo shows that in addition to Dwejra, there are several other such like circular solution subsidence structures in the region. These were all formed millions of years ago, during Miocene times . Solution subsidence structures in the Maltese Islands were first investigated in detail by Pedley in 1974.

The Dwejra and Xlendi regions exhibit a series of interesting and important geological, geomorphological, tectonic and palaeontological features and have, on this account, been recently declared 'National Heritage Protected Sites'.

Typical Geomorphology of Rock Formations

The elements — wind, water and sea — all have a destructive effect on rocks and cause weathering, solution and erosion. When acted upon by the elements, each rock type or geological Formation yields characteristic surface features — depending mainly on the particular composition of that Formation. The study of the rock shapes so formed is known as 'geomorphology'.

Reviewing Gozitan rock formations from above downwards (i.e. starting with the youngest) it will be seen that the Upper Coralline Limestone characteristically tends to form plateaus. On account of the extensive erosion that has affected Gozo, these plateaus have been split into

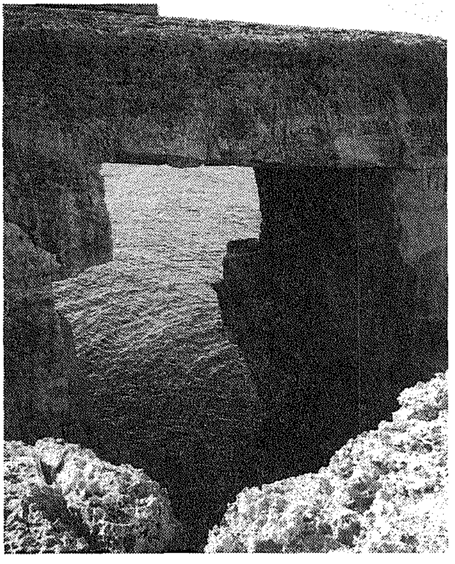

Figure 6. A "window" in the Lower Coralline Limestone at Wied il-Mielaħ, Gozo. *Photo: George Zammit Maempel*

smaller units of clay hills with flat tops (*Mesas*). The underlying Greensands are very rarely exposed horizontally and their vertical exposure tends to form a thick scum at surface with underlying cavitation, thereby setting a treacherous trap for the unweary climber.

In addition, on account of the underlying unstable Clay base and of the tendency of clays to produce a 45° slope, the edges of the overlying Upper Coralline Limestone and Greensand get undermined and break off. Some of the detached boulders roll downwards over the underlying Formations, but others get trapped at the base of the Upper Coralline Limestone and form the characteristic *Irdum* or undercliff. When the fragmentation of the overlying protective Upper Coralline Limestone and Greensand is complete, the Clay will ultimately be reduced to a wedge or even a cone with a few fragmented boulders on top, as *Is-Salvatur* at Marsalforn. In spite of its shape, this is not a volcano, but merely the product of severe erosion. The typical 45° Clay slopes mentioned above, tend to develop deep Gullies as a result of the action of rain water draining down their surface. At times, they are also littered with boulders that have rolled down from the unstable margins of the overlying Upper Coralline plateau and Greensand.

Owing to the relatively small extent of the Globigerina Limestone exposures and the great relief contrast in Gozo, the typical undulating landscape produced by this Formation in Malta is not a very prominent feature of the Gozo landscape. Here, more characteristically, the Globigerina Limestone exhibits horizontal hard grounds. These are formed by the exposure of the flat upper surface of the hard Phosphatic Bed (PB1) overlying the Lower Globigerina Limestone Division. West of Marsalforn, in the region of the salt pans at Xwejni, Nagħag il-Baħar and beyond, the perfectly level horizontal upper surface of the Phosphatic Bed has been used as an excellent base for an asphalted road. At il-Kappar, on the limits of Għarb, the differential weathering of the over- and under- lying soft Globigerina Limestone Divisions provides excellent mute evidence of the hardness of this Phosphatic Bed.

Another characteristic of the Gozo Globigerina Limestone is the formation of conical hills — Qolla l-Bajda and Qolla s-Safra, both in the region of Marsalforn, are typical examples. At Qolla l-Bajda the upper division of the Globigerina Limestone is further subdivided into greyish and whitish elements — a feature not seen in the Maltese landscape.

The Lower Coralline Limestone produces typical sheer-cut cliffs, with sea caves at their base (Figure 5). These are the result of the constant mechanical (battering) action of the waves assisted by their solvent action on the limestone. In addition, the cliffs are generally associated with an overlying platform formed by the receding softer Globigerina Limestone as a result of differential weathering. This feature is markedly evident at il-Miġra.

As Lower Coralline Limestone rocks are hard and well stratified, sea caves tend to have a horizontal roof. If cave formation is in a promontory or a narrow headland, the quadrangular opening or cave so formed tends to communicate with the other side to form a 'Window'. The 'window' at Dwejra and at Wied il-Mielaħ (Figure 6) are typical examples. 'Windows' are doomed to collapse with time, for the wider they get, the greater is the tendency for them to develop a tension crack at the middle of their lintel (the horizontal rock-bed bridging the open space), gradually leading to their collapse and the formation of an isolated column (known as *stack*) a few metres from the headland. The 'window' at Dwejra and that at Wied il-Mielah have both already developed the ominous median crack on their horizontal lintel, so that their fate is already sealed.

Conclusion

The visitor to Gozo is, undoubtedly, aware of most of the landscape features recorded herein, but now that his attention has been drawn to their geological origin, he will look at the Gozitan countryside with a different eye — an understanding eye, one that will not only see the charm and beauty of that landscape, but that will also interpret its features geologically. By so doing, the visitor will appreciate nature all the more and will then realise — not only that landscape is merely the outward manifestation of the underlying geology— but also that the island of Gozo is basically sedimentary, has been greatly modified by faults and that it is utterly dominated by erosion and weathering.

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